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Project-Based Learning on Diverse Concepts in a Power Electronic Laboratory

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Project-Based Learning on Diverse Concepts in a Power Electronic Laboratory

Abstract

This paper presents a project-based learning approach to teach the fundamental aspects of a DC motor, half-wave, and full-wave rectifier circuits in a laboratory. The lab's objectives include:

1. Learn about the essential components of a DC motor by constructing a low-cost DC motor kit.
2. Explore practical methods to enhance the design and performance of the DC motor.
3. Explore and build half-wave and full-wave rectifier circuits to learn their application on a light bulb and the DC motor built by students.
4. Obtain practical techniques for reducing noise while measuring motor output voltage.
5. Utilize an oscilloscope to visualize and analyze the input and output of rectifier circuits.

Assessment methods involve prelab quizzes and post-lab reports to evaluate student learning outcomes. The prelab quiz requires building a low-cost DC motor and improving its performance before the lab session. Each student built the DC motor, and in the lab, they verified the motor's functionality. Next, they constructed half- and full-wave rectifier circuits that operated from a 9-14 volt AC voltage from an AC power generator source. Initial testing of the rectifier circuit involves connecting it to a 28 W light bulb to verify that the circuit produces a rectified output response. Then, students focus on building the circuit exclusively around the DC motor and clarify its output rectified response. The final segment addresses rectifying the voltage ripple using the light bulb in parallel configurations with the DC motor.

This paper outlines the assessment strategy and explains student observations and discussions during the lab. The main goal is to educate students on the significance of each component in the DC motor, half-wave, and full-wave rectifier circuit and emphasize safety and conscientious practices when working with AC power systems.

Introduction

This lab is one of the seven laboratories in a 3.5-credit Electric Energy and Machines course. Electrical Energy and Machines is a free major area elective course for the undergraduate Electrical Engineering major at the U.S. Coast Guard Academy. The course is structured to provide essential fields on electric energy and machines in one semester through active hybrid in-person teaching [1].

One of the course's objectives is establishing a secure laboratory environment, allowing undergraduate students to engage in hands-on experiments with high-power systems. This approach has been adopted when designing the course to cover the fundamental concepts of high-power systems. The focus is on providing theoretical foundations and establishing a well-equipped laboratory aligned with the critical topics of the course. Throughout the semester, labs are administered to assess students' comprehension of various key topics in electric energy and machines. This multifaceted approach enhances theoretical understanding and equips students with practical skills, preparing them for the complexities of electrical power and machines in academic and real-world contexts. The course employs a comprehensive assessment strategy that includes weekly quizzes to evaluate individual understanding of theoretical concepts. Also, pre-lab and post-lab quizzes and reports are used to assess students' proficiency in applying theory to real-world power systems.

The first lab provides hands-on experience in wiring high-voltage DC and AC circuits, utilizing Hampden benches and workstations in all labs. The following lab focuses on wiring three-phase wye-wye connections for both balanced and unbalanced load circuits. Lab 3 covers the wiring of three-phase wye-connected sources to delta-connected loads, allowing students to practice balanced and unbalanced delta-load connections. The fourth lab centers around the wiring of a real transformer, with objectives including analyzing, predicting, and measuring the step-down and step-up of loaded and unloaded transformers. The fifth lab delves into the fundamentals of DC motors and rectifier circuits, as presented in the current paper. Lab 6 introduces students to the torque and speed characteristics of series and shunt-connected DC motors. Finally, the last lab teaches students about parallel generators. Detailed descriptions of each laboratory can be found in [1].

Many textbooks cover electrical circuits, electronic devices, and electric machines, including diodes, transistors, MOSFET, rectifier circuits, and AC/DC machinery [2], [3], [4], and [5]. Most institutions worldwide strive to teach these concepts using a practical approach. For instance, Ochs and Miller [6] introduced a laboratory course that applies power electronics to sustainable energy applications. Meanwhile, Engür et al. [7] developed a triple-mode rectifier circuit that can convert AC signals to DC voltage in different modes for various coupling levels at the frequency of 13.56 MHz. Furthermore, Cardoso et al. presented an analytical model of a one-stage rectifier circuit in their study [8]. The model is based on the diode Shockley equation, and the authors claim that it is valid even for operations with very low voltage. Their study aimed to incorporate this model into undergraduate power electronic courses as a valuable learning experience. Rui Hong Chu et al. [9] presented an application of a project-based laboratory to teach power electronics based on a programmable intelligent computer microcontroller and an H-bridge to design a control system. Jianyu Dong et al. [10] discussed collaborative project-based learning, including the course redesign process and the primary pedagogy that impacted student learning. Guo and Yang [11] presented pilot research that adopted project-based teaching and learning to link teacher professional development and student learning. When developing a practical laboratory, it's crucial to educate students on the safety measures and potential effects of AC and DC currents on humans [12].

This paper introduces a project-based learning approach for students to understand motor and rectifier circuits better. The project consisted of two parts. The first part involved constructing low-cost DC motors before the lab. The second part involved working on the half-wave and full-wave diode rectifier circuits during the lab. The focus was on analyzing their responses to various load conditions. This lab combines theoretical knowledge with practical implementation to help students better comprehend these circuit principles. Safety protocols must be followed, and the lab instructor and technician observe students' activities throughout the experiment. This laboratory can assess the ABET students' outcome 5: "an ability to function effectively on a team whose members provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives"[13].

Safety

The Electric Energy and Machines course has several lectures at the beginning of the semester that cover electric power safety [3]. Students learn about the dangers of working with electrical AC and DC currents that can flow through the body. They are advised to be extremely cautious while working on these circuits. A hard copy of the effects of AC and DC currents from the IEEE standard on page 17 in [12] is given to students in the lab handout. Additionally, students are reminded to remove all extra wires in the lab bench area. To ensure maximum safety, the technician or lab instructor checks and monitors the students' circuits before they run high power voltage through the circuit.

Prelab Quiz

Each student builds a small DC motor [14], as shown in Figure 1 as the prelab quiz. This kit helped students learn about fundamental parts of DC motors, such as the assembly of the stator based on a permanent magnetic field, the rotor and commutator assembly, brushes, and the impact of the voltage source.

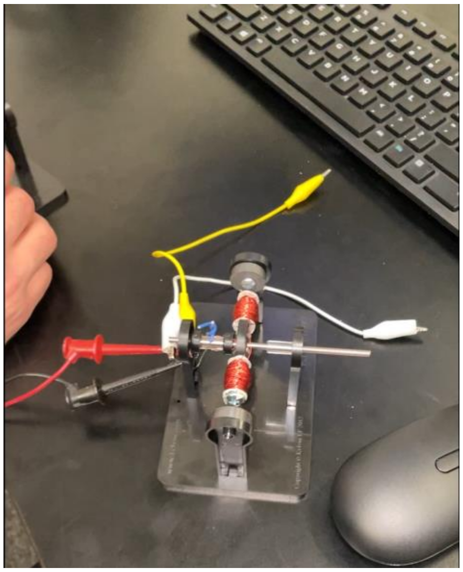
Figure 1: Pre-lab Quiz Building a DC motor

The prelab assessment questions were: 1) Total number of magnets used on the stator, 2) Number of troubleshooting with the magnets, 3) Clarify how many times students had to rebuild the stator, 4) Clarify how many times students had to rebuild the rotor, 5) Number of issues with the battery and voltage source generator, 6) Specify how many times they attempted to rewire the brushes.

The students' assessment results for the pre-lab quiz are shown in Figure 2. The results showed that most students had problems wiring the brushes. Some students had to rewire the rotor. Two students made the motor work correctly the first time. Four out of fourteen students could not complete the motor work. Individual students learned about the fundamental parts of the motor, and they investigated the impact of the proper design of the brushes and commutator via troubleshooting.

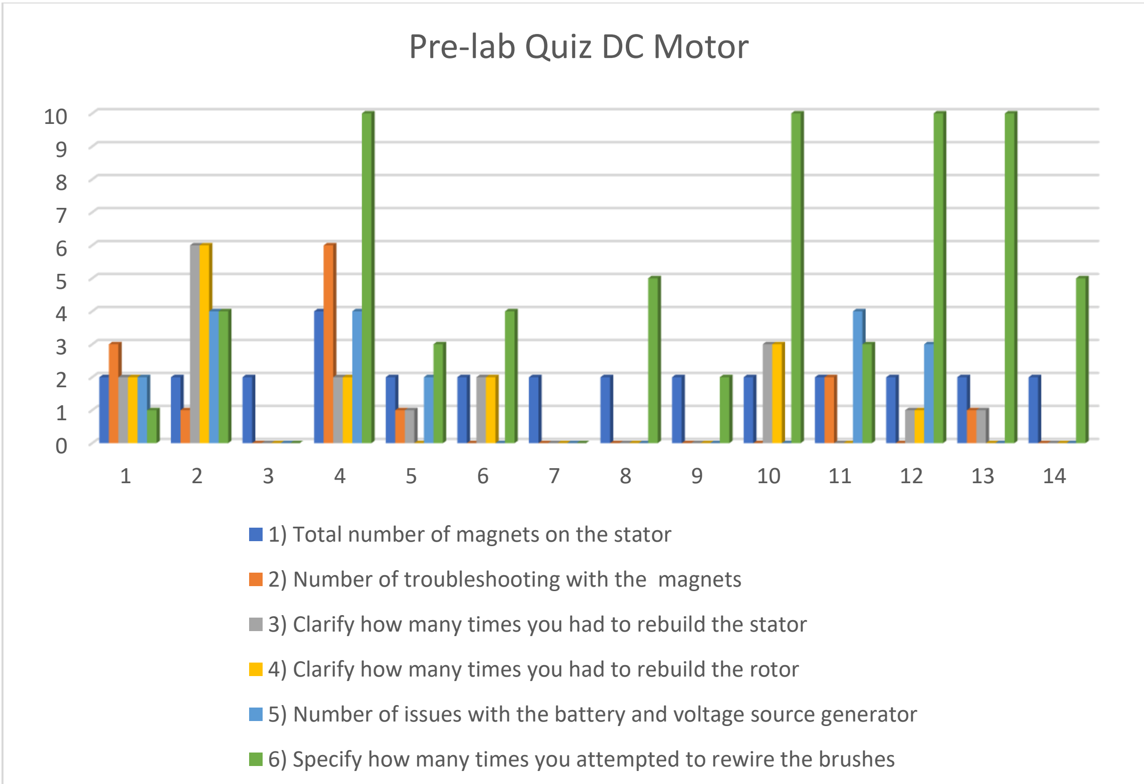

Figure 2: Assessment of Pre-lab Quiz

Some of the students' experiences with the pre-lab quiz were, "We built a DC motor kit that used stator magnets, rotor windings, commutator wires, and wire brushes. First, we built the rotor by winding approximately 40 feet of wire on each end, ensuring they were in the same direction. Then, we put together the stator and added wire brushes so that they made contact with the commutator wires. When building this DC motor, I learned that the voltage must be enough so the magnetic field can spin the rotor through. I also learned that the brushes must contact the commutator at the right time so that the motor makes efficient use of the magnetic field. Added more voltage and got the motor to work. Ended up with the signal generator for running the motor." The range of voltage reported by students to run the motor was between 8.23 and 14 volts, and the current was between 1-3 amps.

Lab Procedures

The lab procedures are in two parts. First, students apply half-wave rectifier circuits and full-wave rectifier circuits for different load conditions. The schematic block diagram of the lab is shown in Figure 3.

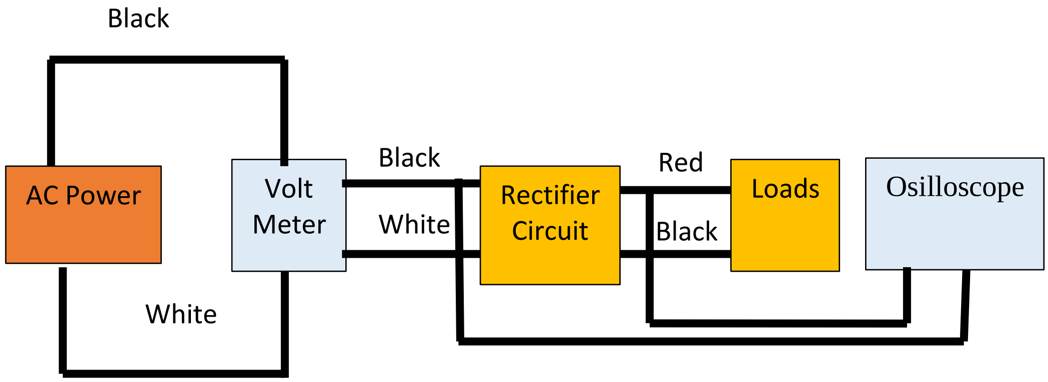

Figure 3: The schematic block diagram of the lab

Part A: Half-wave Rectifier Circuit

In the first part of lab, students learn about the half-wave rectifier circuits input and output responses with three different load conditions: A) The load is only a light bulb, B) The load is the motor that they build, and C) The load is the light bulb parallel to the motor.

A 3D printer box was provided for the four diode installations in rectifier circuits, as shown in Figure 4. This box increases the safety of the lab environment. This approach offers a superior alternative to traditional breadboards, which may not provide adequate protection against accidental contact with diodes. Students apply a half-wave rectifier circuit in Fig 4. a, where the load is only a light bulb, and measure the input and output responses via an oscilloscope. Then, they changed the load to be only their own DC motor from the pre-lab quiz and analyzed the results. During the lab, each team of two students performed more troubleshooting and had at least one working motor to apply as one of the loads for the rectifier circuit. In this measurement, they can see the ripple in the DC motor output response. After that, they connected the DC motor in parallel with the light bulb in Fig 4. b, and they could clean the ripple in the output response.

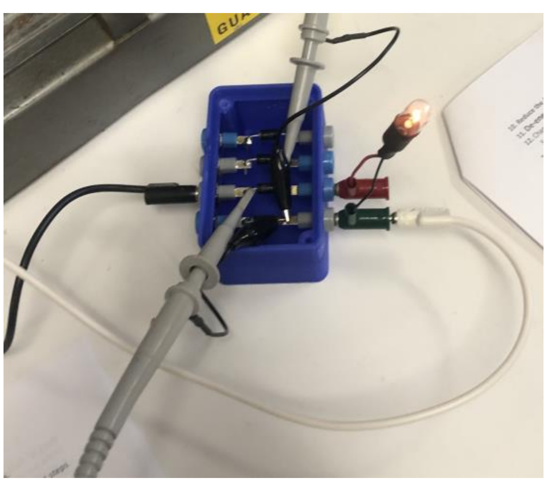

Fig 4. a

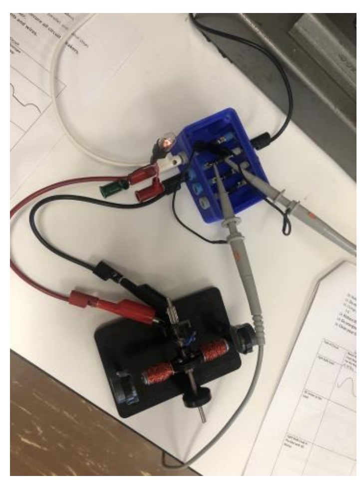

Fig 4. b

Figure 4: A half-wave rectifier circuit with only a light bulb as the load (Fig 4. a) and a parallel connection of the light bulb and DC motor as the load (Fig 4. b)

We encountered difficulty generating AC voltages in the 9-14 volts range during our lab experiments. Most of the equipment available in our laboratory could only generate up to 5 Volt AC voltages. We used a Hampden high-power electric workstation, which more safely generated a variable AC voltage. One of the measurement results of the input in yellow and output in green of the half-wave rectifier collected by students is shown in Figure 5. To measure the input and output voltage of a half-wave rectifier circuit in a single window, students connected two channels of an oscilloscope simultaneously and clarified the responses.

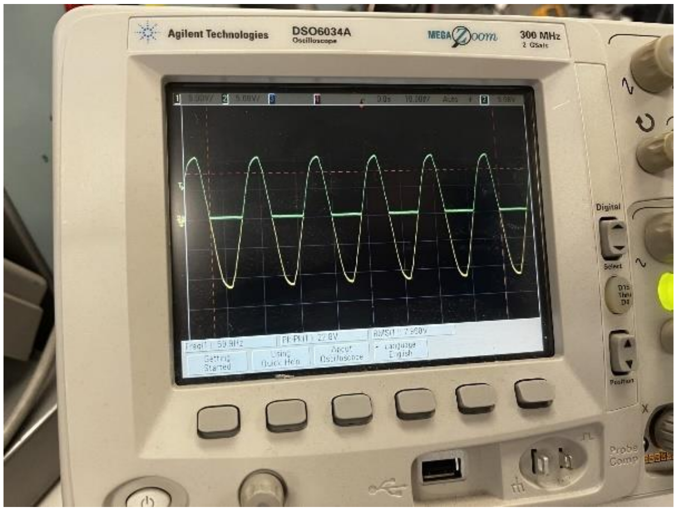

Figure 5: Half-wave rectifier circuit input (yellow) and output (green) responses for the DC motor in parallel with a light bulb

Some of the students' observations of this part of the lab were, "The input response is a sinusoidal voltage input. The output response of the half-wave rectifier is the same sinusoidal voltage input except only the positive part. This is because the diode only allows current to flow in one direction and blocks current from the other. The input and output for the light bulb and light bulb in parallel with the DC motor look very similar."

Part B: Full-wave Rectifier Circuit

In the second part of the lab, students analyzed full-wave rectifier circuits input and output responses with three different load conditions: A) The load is only a light bulb, B) The load is the motor that students build, and C) The load is the light bulb parallel to the Motor students build.

A parallel light bulb and DC motor connection are applied to the full-wave rectifier circuit. The issue with this measurement was the ground condition of the oscilloscope, which is internally connected. We aimed to measure a rectifier circuit's input and output on a single oscilloscope window. A solution to measure the full-wave rectifier circuit input and output data simultaneously was to measure each half-wave of the rectifier signal separately. We asked students to create a clever way of measurement. For example, one group connected Chanel 1, which measures the positive half of the sinewave; Chanel 2, which measures the negative part of the sinewave; and Chanel 3, which is used to measure the input of the rectifier circuit. They apply a math function on an oscilloscope to create a final sign wave reading, as expected from a full-wave rectifier circuit. Students absorbed that if they apply only the DC motor as the load to the rectifier circuit, the response is ripple. However, when they added the light bulb in parallel with the DC motor, they could clean the ripple extensively.

The report of a group of students who measured a full-wave rectifier circuit is shown in Fig 6. a and Fig 6. b. In Fig 6. a, the input signal is represented in blue, the positive half-wave is shown in yellow, the negative half-wave is green, and the overall output response with the math function is purple. The measurement was taken using an oscilloscope to measure the voltage of a DC motor and a light bulb connected in parallel. In Fig 6. b, the full-wave rectifier circuit measurements are shown with blue as the input and purple as the circuit output.

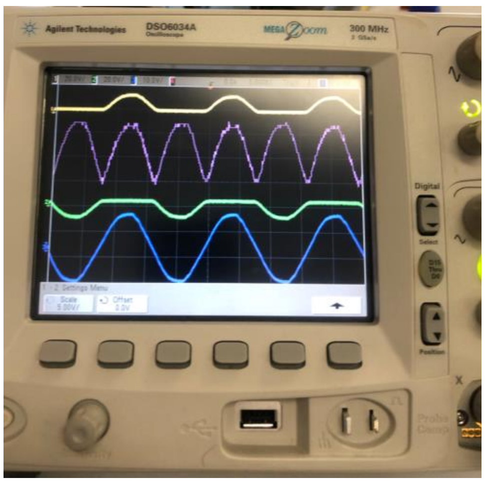

Fig 6. a

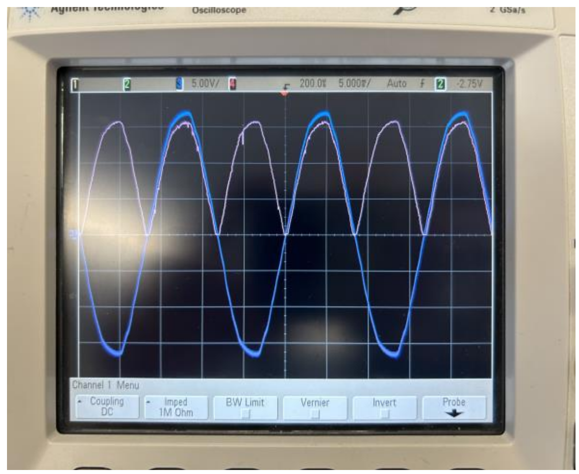

Fig 6. b

Figure 6: Full-wave rectifier circuit measurement responses for the DC motor in parallel with a light bulb in Fig 6. a: input (blue), positive half-wave (yellow), negative half-wave (green), and overall output (purple), and in Fig 6. b, input (blue) and overall output (purple)

The students' assessments are in both pre-lab and post-lab reports. They submitted the post-lab report to explain how they measured the rectifying responses in the oscilloscope, compared the impact of loads on each circuit and analyzed the difference between the output response of both circuits. Their grades were excellent. Some of the practical applications of diodes in the EEM course are in AC to DC converter and DC to DC boost converter; the knowledge gained from studying diodes, rectifier circuits, and DC motors would apply in their capstone project, where they will design, build, and test a hybrid power plant. They will analyze the system's power by measuring the voltage and current.

Conclusions

This paper presented an application of project-based learning in a laboratory. Through hands-on experiments, students demonstrated an understanding of the fundamental aspects of DC motor operation, half-wave, and full-wave rectifier circuits input and output responses. They obtain proficiency in troubleshooting various motor issues and gain insight into the multifaceted nature of motor functionality. Moreover, the project's innovative approach includes restructuring equipment and enhancing safety and efficiency within the lab environment in the AC voltage generator and a housing setup for building the rectifier circuit. Providing a 3D printer box for diode installations in rectifier circuits offers students a more controlled testing environment than traditional breadboards without touching any diodes. Including a light bulb in testing conditions aids in circuit assembly accuracy while using the DC motor as a load, which allows students to visualize output ripple. Furthermore, integrating the light bulb in parallel with the DC motor clarifies a method for minimizing ripple in the DC motor output voltage response. This comprehensive approach fosters deeper comprehension and practical application of electrical engineering concepts in students. This laboratory can assess the ABET students' outcome 5: "an ability to function effectively on a team whose members provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." [13]

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